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SIMULATION OF DARLINGTON SHUTDOWN AND REGULATION SYSTEMS

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SIMULATION OF DARLINGTON
SHUTDOWN AND REGULATION SYSTEMS

ABSTRACT

This report describes the development of a simulation of the Darlington Nuclear Generating Station shutdown and regulating systems, DARSIM, done under a contract to the Atomic Energy Control Board. The DARSIM program simulates the spatial neutron dynamics, the regulation of the reactor power, and Shutdown System 1, SDS1, and Shutdown System 2, SDS2, software. The DARSIM program operates in the interactive simulation (INSIM) program environment. DARSIM was not installed on the AECB's HP-1000 computer as originally intended. Contractual obligations were met by the contractor's supplying a version of DARSIM operating on an IBM PC for the exclusive use of the AECB.

RÉSUMÉ

Ce rapport décrit la mise au point d'un programme de simulation pour les systèmes d'arrêt et de régulation de la centrale nucléaire Darlington. Ce travail a été fait dans le cadre d'un marché avec la Commission de contrôle de l'énergie atomique du Canada (CCEA). Le programme DARSIM (abréviation dérivée de "Darlington simulation" : simulation de Darlington) simule la dynamique spatiale des neutrons, la régulation de la puissance du réacteur et le logiciel des systèmes d'arrêt d'urgence du réacteur (SAU 1 et SAU 2). Le programme DARSIM opère en milieu INSIM (abréviation dérivée de "Interactive Simulation" : simulation interactive). DARSIM n'a pas été introduit dans l'ordinateur HP-1000 de la CCEA comme prévu. Les obligations du contrat furent satisfaites par la remise d'une version de DARSIM pour un IBM PC, à l'usage exclusif de la CCEA.

DISCLAIMER

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TABLE OF CONTENTS

ABSTRACT i

A. INTRODUCTION 1

B. DARLINGTON SIMULATION (DARSIM) MODEL 1

1. System Model 1
1.1 System Modules 1
1.1.1 Neutronic, Regulation and Shutdown System Modules 1
1.1.2 Computerized Trip Parameter Modules 2

1.2 Time Simulation 3
1.2.1 Continuous Time Simulation 4
1.2.2 Discrete Event Simulation 4

2. Program Structure 4
2.1 Modular Structure 4
2.1.1 Input Data Files 5
2.1.2 Initialization Routines 5
2.1.3 Screen/Printer Output 5
2.1.4 Module Output to File 5

2.2 User Interaction 6
2.2.1 Model Generation 6
2.2.2 Input Data File Selection 7
2.2.3 Keyboard Interrupt Menu 7
2.2.4 Prompting 9
2.2.5 Keyboard Input Error Checking 9

3. Simulation Modules 10
3.1 Neutron Spatial Dynamics, Reactor Regulation and Shutdown Systems 10

3.2 Shutdown Systems' Trip Computers 10

3.3 Simulation Fidelity 10

3.4 Operating Environment 10

4. Computation Requirements 11

C. RESULTS 11

References 11

SIMULATION OF DARLINGTON SHUTDOWN AND REGULATION SYSTEMS

A. INTRODUCTION

This report describes the development of a computer program for the simulation of the Darlington Nuclear Generating Station shutdown and regulation systems under contract to the Atomic Energy Control Board of Canada, AECB. This project was done to provide AECB staff with a tool to assess the effectiveness of the trip computers proposed for use in Shutdown System 1, SDS1, and Shutdown System 2, SDS2, of the Darlington NGS. The DARSIM program is patterned after the concepts of SLISIM (Ref. 1). Simulation of the SDS1 and SDS2 trip computers' software is based on documentation provided to the contractor (Ref. 2,3,4,5). Simulation of the SDS1 and SDS2 trip computers' software is based on references 3 and 5 which give the proposed software to meet the functional specifications described in references 2 and 4. Simulation of the spatial neutron dynamics within DARSIM is based on the SMOKIN code (Ref. 6).

B. DARLINGTON SIMULATION (DARSIM) MODEL

1. System Model

The system model is constructed from a selection of the eight available modules. The modular nature of the program allows for expansion of the number of program modules.

1.1 System Modules

The present eight modules can be divided into two groups:

- group 1 comprises modules 1 to 6 which simulate the neutronic, regulation and shutdown systems.
- group 2 comprises modules 7 and 8 and simulates the trip computers of the Darlington NGS shutdown system 1 and shutdown system 2.

1.1.1 Neutronic, Regulation and Shutdown System Modules

The six modules in this group are:

- Module 1 = SPANK
- Module 2 = SDS-N.SIG.
- Module 3 = SDS1-SOR
- Module 4 = SDS2-PI
- Module 5 = RRS-CONTINUOUS
- Module 6 = RRS-DISCRETE

(a) SPANK: this module simulates the spatial analog neutron kinetics and computes:

- neutron spatial dynamics,
- delayed neutron precursor concentrations,
- Xe and I concentrations and associated reactivity,
- power feedback reactivity,
- reactivities due to regulation, shutdown system devices and other user-defined perturbations.

(b) SDS-N.SIG.: this module simulates the response of the neutron sensors and computes:

- in-core neutron detectors' response,
- ion chambers' response,
- ion chambers' log rate.

(c) SDS1-SOR: this module simulates actuation of the shutoff rods (SOR) which comprise the final elements of SDS1 and computes:

- insertion of shutoff rods into the reactor core as a function of time after initiation of a SDS1 trip.

(d) SDS2-PI: this module simulates actuation of the poison injection (PI) system which comprises the final elements of SDS2 and computes:

- insertion of highly neutron absorbing liquid (poison) into the reactor core as a function of time after initiation of a SDS2 trip.

(e) RRS-CONTINUOUS: this module simulates the reactor regulating system devices whose motion is of a continuous nature (reactor regulating system - continuous). The module computes:

- positions of liquid zone level control valves,
- levels and volumes of H_2O in liquid zone controllers,
- positions of mechanical control absorbers (MCA's) and adjuster rods (AR's),
- position as a function of time for user-defined induced perturbations

(f) RRS-DISCRETE: this module simulates the action of the digital computer control of the bulk and spatial neutron flux (reactor regulating system - discrete). The module computes:

- the bulk and spatial power errors,
- the bulk and spatial components of the liquid zone controller's valve lifts,
- response to requested power changes.

1.1.2 Computerized Trip Parameter Modules

The two modules in this group are:

- Module 7 = S1TCMP
- Module 8 = S2TCMP

(a) S1TCMP: this module simulates the software and hardware of the Darlington shutdown system computers for shutdown system number one, SDS1 (Ref. 2,3). The module computes:

- compensated trip setpoints for the neutron overpower trip detectors based on the detector signals output from module 2*,

- neutron signal conditioning of process parameters based on output from module 2* including computation of the detectors' compensation,

- trip setpoints which are a function of neutron power,

- enable/disable conditioning of trip parameters at the specified power levels,

- channel and shutdown system trips by the neutronic and the process trip parameters.

(b) S2TCMP: this module simulates the software and hardware of the Darlington shutdown system computers for shutdown system number two, SDS2. The module computes:

- compensated trip setpoints for the neutron overpower trip detectors based on the detector signals output from module 2*,

- neutron signal conditioning of process parameters based on output from module 2* including computation of the detectors' compensation,

- trip setpoints which are a function of neutron power,

- enable/disable conditioning of trip parameters at the specified power levels,

- inhibition of a SDS2 low flow parameter trip by the power rundown discriminator,

- channel and shutdown system trips by the neutronic and process trip parameters.

1.2 Time Simulation

Scheduling and execution of the model's modules requires a capability for both continuous and discrete event simulation.

The program executes a complete cycle of the selected modules at a fixed simulation time interval of 0.01 seconds. Selected modules are executed only if the current simulation time minus the last execution time is equal to or exceeds the module's execution time interval.

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*If module 2 is not selected, default values for the neutron signals are used. These values can be changed by the user.

1.2.1 Continuous Time Simulation

The output of modules 1 to 5 is computed based on a continuous time simulation. The output at the selected times is integrated over the time interval. An exponential integration routine is used to simulate rapid changes while an Euler integration routine is used to simulate slow changes such as those due to Xenon, Xe, and Iodine, I.

Output of modules 1 to 5 is computed at the same time value and uses the same time interval.

1.2.2 Discrete Event Simulation

The output of modules 6, 7 and 8 is computed based on samples taken at discrete time intervals. This discrete event simulation capability is required to simulate the:

- bulk and spatial control of the neutron power by the station's direct digital control computers which is simulated by module 6,

- SDS1's trip computers' software functions which are simulated by module 7,
- SDS2's trip computers' software functions which are simulated by module 8.

Capability is provided for input of different sampling intervals for: (a) both bulk and spatial control, (b) SDS1 trip computers and (c) SDS2 trip computers.

The asynchronous nature of the physical system is simulated by allowing the user to input a phase factor. This phase factor shifts the module's sampling interval relative to the basic time interval of the process neutronics. For example, with a basic time interval for module 1 of 50 m sec. and a discrete event sampling time interval of 100 m sec., the phase factor allows the first (and subsequent) time samples to be taken at times of 50 or 100 m sec. delay.

2. Program Structure

The DARSIM program had been developed to operate within an interactive simulation (INSIM) system environment. The main features of the INSIM program are its:

- modular structure,
- extensive user interactive simulation capabilities.

2.1 Modular Structure

The modular structured programming capability gives the user flexibility in selection of modules to create his model and to add additional modules if required. To preserve this modular independence, each module has its own separate input, output and parameter change and examine routines.

2.1.1 Input Data Files

Each module has its own input data file. These data files are considered to be the reference data bases. With separate data files for each module, the user does not have to edit the input data file each time he alters the number of modules in his model. Only the input data files for the selected modules are read by the program.

All available data on each of the files are read in. The user has the capability to alter these data after the final input data file has been read in. In the case of reactivity perturbation data, all the available perturbation data are read in but on completion of the read the perturbation initiations are disabled. The user selects from the available perturbations which one he wishes to initiate by enabling the corresponding perturbation.

Provision is made for the user to read in other data files by changing the default input file names on initial setup of the model.

N.B. The input data files for modules 7 and 8 contain not only the parameter values but also a physical description of the parameters and variables used by the module.

2.1.2 Initialization Routines

A common initialization routine is used for modules 1 to 6. This arises because of the interdependence of this group of modules. This initialization routine sets the initial values of the modules' variables and establishes the initial reactivity balance with the reactivity devices at their given position.

The initialization routines for modules 7 and 8, SDS1 and SDS2 trip computers respectively, set the module variables to their initial conditions.

2.1.3 Screen/Printer Output

The progress of the simulation is monitored through output of variable values to the screen and to a printer. If a printer is not immediately available, output destined for the printer can be re-routed to a file. Two different groups of 33 variables selected from the same common group of 191 can be output at a time interval selected by the user. Default values are provided for the two groups of 33 variables and the output time interval. These default values can be changed by the user any time during the simulation. The selected group of variables for both the present time step and the immediately preceding time step are presented on the same screen. Actuation of individual trip parameters and shutdown system trips are identified at the bottom of the screen.

2.1.4 Module Output to File

The user can select output options from each module to a file.

This output can be reviewed at any time during the simulation and supplements the screen/printer output.

Three output options are provided for each module which are:

- 0 = no output,
- 1 = partial output,
- 2 = full output.

The default value for each module is 0 but this can be changed for each module by the user during initial setup of the model.

N.B. Output options are established on initial setup of the model and cannot be changed during the simulation.

The user is given the option to change the output file name from its default name, DAR001.

In addition to the above output, a standard SMOKIN type output is written to file DARSMO.

2.2 User Interaction

The INSIM program provides a "user-friendly" operating environment through provision of:

- menus from which user makes selections,
- prompts,
- extensive error checking of user keyboard input,
- windowing features,
- a keyboard interrupt capability which allows the user to interrupt the simulation at the end of a basic time cycle, change parameters and then continue with the simulation.

The above INSIM characteristics provide the DARSIM user with the following features:

- model generation from available modules,
- input data file selection,
- menu (option) selection on keyboard interrupt of simulation,
- prompting,
- keyboard input error checking.

2.2.1 Model Generation

On initial startup the user is queried whether the case to be simulated is a restart of a previously "saved" simulation. If Yes, the user is prompted for the restart filename if it is not the default filename, DARRS1. For a restart case, the modules used to generate the model are those that were used in the previous simulation. If not a restart case, the user selects from the eight available modules, which are presented in sequence, only those needed to construct his model.

N.B. At present it is recommended the user select any one, two or all three of the following module sets:

- modules 1 to 6,
- module 7,
- module 8.

Following module selection the user is prompted for the input data file names for his selected modules, if the input data is on files other than the default files. (See following Section 2.2.2.)

During the initial setup, the user is prompted for selection of an option for output of the values of the modules' variables to a file. (See previous Section 2.1.4.)

After initial selection of modules and output options, the user is presented with a summary of his model modules and the selected file output options. At this stage the user is given the option to change his options through a restart of the initial selection process.

2.2.2 Input Data File Selection

Reference data base files are provided for modules 1 to 8. These data files have been discussed in section 2.1.1. The user is provided with a capability to change the majority of the input data for the modules before the start of the simulation. However, these changes apply only to the current simulation and would have to be re-entered for each simulation. For simulations which require considerable changes to the input data, provision exists for the user to create a new data file and use this file as input instead of the default file.

2.2.3 Keyboard Interrupt Menu

The keyboard interrupt menu is displayed following each keyboard interrupt of the simulation and also following completion of reading the input data files for all the selected modules. This latter display of the keyboard interrupt menu allows the user to change module parameters prior to module initialization and start of the simulation.

The available keyboard interrupt options are:

Option	Item
1	Change input parameter values
2	Change printer output parameters
3	Change screen output parameters
4	Status of S1TCMP logical variables
5	Status of S2TCMP logical variables
6	Save for restart
7	Examine value of variables
8	Review variable history
9	Continue with simulation
10	Stop execution of code

1. Change input parameter values: this option enables the user to change values of the modules' parameters. Selecting

this option results in a layered menu; the first menu displays the modules from which the user selects the module whose variables he wishes to change. After selection of the module, the user is presented with the list of the module parameters which he can change. This routine is capable of changing module parameters which are identified by up to three-dimensioned arrays.

N.B. If a simulation of a reactivity perturbation is required, the user has to specify the type of perturbation to be initiated by this "change input parameter" routine.

2. Change printer output parameters: this option allows the user to change the printer output time interval*, the phase factor (see Section 1.2.2) and the variables that will be output to the printer. The user can select any 33 variables from a list of 191. A default list is provided which can be altered by the user. This capability allows the user to select the format (row and column) for presentation of the variables as the list of 33 can be selected in random order from the available list of 191.

3. Change screen output parameters: this option parallels option 2 and allows the user to change the screen output time interval*, the phase factor (see Section 1.2.2) and the variables that will be output to the screen. The user can select a group of 33 variables (a group which is distinct from the group of 33 printer variables) from the list of variables which is a common selection list for both the printer and screen selection sets.

4. Status of S1TCMP logical variables: this option reviews the status of all logical variables and displays on the screen those which are TRUE along with the array name, element number and physical description of the variable. It should be noted that the normal state, except for a few variables, is FALSE. The variables initially set to true can be determined by requesting this option before the start of the simulation.

5. Status of S2TCMP logical variables: this option is identical to option 4 but presents the status of S2TCMP logical variables which are set to TRUE.

6. Save for restart: this option allows the user to save the current status of his simulation. The simulation can be continued at a later time using this file as the input.

7. Examine value of variables: this option allows the user to examine variables and parameters for the modules during the simulation. A layered menu structure and approach,

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*The output time interval and phase factor are common for both the printer and screen output.

common to option 1 (see option 1 above) is used. In addition to the parameters that the user is allowed to change under option 1, the user can also examine the values of the module variables.

8. Review variable history: this option allows the user to review the modules' output written to file (see Section 2.1.4). The number available for review at any one time is fixed at 30. This list can be composed of variables selected from the different modules. Successive review of different groups of 30 values can be accommodated. In addition, the user has the option to obtain a printer-plot which can give a simultaneous display of up to four variables versus time on the screen. Only the first four (excluding the time variable which must be the first variable) will be displayed for any selected group of up to 30 variables. Displays of different groups of four variables can be obtained by successive calls of this option.

9. Continue with simulation: this option results in continuation of the simulation from its current status.

10. Stop execution of code: this option results in termination of the simulation and closure of files used during the simulation.

2.2.4 Prompting

The user is assisted in setup and control of the simulation by use of screen windows combined with prompt commands. Response to prompts can be of the following form:

- C/R, pressing "carriage return" leaves the default value unchanged or permits a keyboard entry to change the default parameter,
- a Y/N (Yes/No) response to a query,
- a specific response as defined in the prompt statement.

In addition to the prompts, messages are output to the screen to inform the user of the operational status of his simulation. These messages are in addition to the normal screen output (see section 2.1.3).

2.2.5 Keyboard Input Error Checking

Extensive error checking of user input from the keyboard is incorporated into the program. Input variables are checked for type and array variables are checked for range. This reduces the probability of inadvertently changing module variables or inputting data which could disrupt the simulation. Furthermore, most keyboard input changes are echoed on the screen to the user for verification. If the wrong value was entered, the user can input the correct change.

3. Simulation Modules

The DARSIM program modules can be divided into two groups which are those simulating:

- the neutron spatial dynamics, the reactor regulation system and the shutdown systems' final elements,
- the shutdown systems' trip computers.

3.1 Neutron Spatial Dynamics, Reactor Regulation and Shutdown Systems

The simulation of these systems is based on input data for the Darlington NGS provided to the contractor. As noted previously, only a point model or bulk reactivity simulation of the shutdown systems' final elements exists in DARSIM. Furthermore, reliable input data was provided to the contractor for only shutdown system 1 final elements.

3.2 Shutdown Systems' Trip Computers

Modules 7 and 8 simulate the proposed SDS1 and SDS2 Darlington trip computers' software. Each of the three channelized trip computers for each shutdown system is simulated. The log and log rate ion chamber signals and the in-core detector signals used by the trip computers are obtained from module 2.

3.3 Simulation Fidelity

Documentation of the validated software for the Darlington SDS1 and SDS2 trip computers did not exist at the time this project was initiated. Emulation of such software in DARSIM was based on the available preliminary software descriptions contained in references 3 and 5. Individual subroutines emulating the trip computers' software were verified to meet the functional intent embodied in the software design descriptions. No Darlington NGS test case results were available to verify the spatial neutron dynamics portion of the code.

Assumptions embodied in the DARSIM program and possible discrepancies in the supplied data have been brought to the attention of the AECB. No extensive effort to resolve these potential discrepancies has been made since this was beyond the scope of the present contract.

3.4 Operating Environment

As noted previously, the DARSIM simulation operates within the INSIM system environment. The INSIM operating system environment is a proprietary program that had been developed independently by the contractor for operation on microcomputers, particularly the IBM PC. INSIM incorporates the latest interactive and user-friendly features.

The original contract called for the contractor to install the DARSIM program on the AECB's HP-1000 computer. This was found to be impractical if the agreed schedule was to be met because of circumstances beyond the contractor's control. It was agreed contractual obligations would be fulfilled by the contractor's supplying a version of DARSIM for the exclusive use of AECB staff which could operate on an IBM PC.

4. Computation Requirements

The DARSIM simulation was written in Microsoft FORTRAN Version 3.2. Microcomputer hardware requirements for program operation are:

- RAM of approximately 640k,
- hard disk,
- 8087 co-processor,
- real time clock access.

The program can operate without the 8087 co-processor but at considerable reduction in speed of execution.

C. RESULTS

A simulation of the Darlington NGS regulation and shutdown systems, DARSIM, has been installed and checked out on an IBM PC of the AECB. No significant discrepancies from expectations have resulted. The DARSIM program cannot be validated because no adequate validation model exists. Since the Darlington SDS1 and SDS2 trip computers' software has not yet been finalized and validated, it must be expected that changes in the DARSIM programming emulating the SDS1 and SDS2 trip computers will be required to reflect the final validated system.

References

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2. "SDS-1 Trip Computer Functional Specifications, Rev. 1", AECL-proprietary.

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4. "SDS-2 Trip Computer Functional Specifications, Rev. 1" AECL-proprietary.

5. "Shutdown System Number 2: Trip Logic Software, Rev. 3", AECL-proprietary.

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